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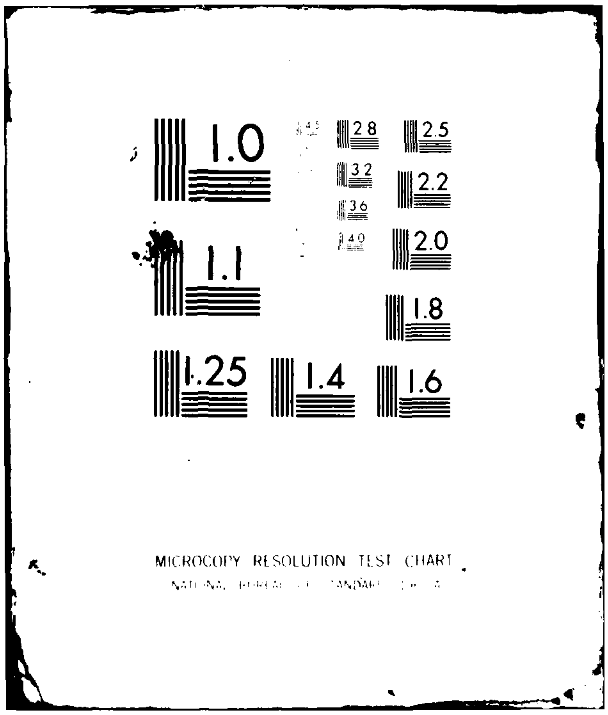
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TECHNICAL REPORT RG-81-24

NORTH-FINDING MODULE EVALUATION

S. G. McDaniel
H. V. White
Guidance and Control Directorate
US Army Missile Laboratory

April 1981

U.S. ARMY MISSILE COMMAND
Redstone Arsenal, Alabama 35809

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

A Litton north-finding module was studied to determine its absolute azimuth accuracy and repeatability. Results indicate the north-finding module can determine azimuth heading with reasonable accuracy in a laboratory environment. The unit will be used in an in-house program to demonstrate its potential as an azimuth heading transfer system for tactical missile systems which do not have on-board self-alignment capability.

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CONTENTS

I. INTRODUCTION

The Litton north-finding module (NFM) provides, as its name implies, virtually automatic sensing of true north. The azimuth heading of the NFM is determined by a gyrocompass basically consisting of a Litton G-7 two-degree-of-freedom, dry, tuned-rotor gyro. The NFM uses a normal pendulum configuration with the gyro mounted in a container and suspended by a single metallic wire. This pendulum is enclosed within another container with a fluid used for damping completely filling the space between the two containers.

To achieve useful NFM accuracy for tactical missile aiming, a gyro would normally have to exhibit drift performance of better than 0.005 degree/hr. This is generally exhibited by an inertial navigation grade instrument, whose cost is not compatible with low-cost goals. The simple expedient of rotating the entire sensor assembly 180° and making a second measurement eliminates the day-to-day gyro drift repeatability, hence, a lower cost gyro can be used. For the short NFM measurement times, all but relatively short-term correlated noise and thermal transients due to turn-on are also eliminated. When coupled with the pendulous suspension, it removes any error caused by the gyro horizontal axis not being exactly horizontal.

The rotation of the sensor unit is achieved by a small dc motor that drives the assembly from one stop to another nominally 180° apart. By rotating about the spin axis, this rotation can be made in about 5 seconds without requiring excessive torquing rates from the gyro.

The gyro is pulse-rebalanced, providing output pulses that represent about 0.04 arc second displacement. These pulses are accumulated in an up-down counter in such a way that the residual in the counter after two rotations is the difference between the rates measured by the gyro in the 0° and 180° position.

The data in the two registers are processed in a digital computer which contains a 12-bit microprocessor. The microprocessor provides digital filtering of the data and computes the azimuth angle between north and the reference on the NFM case.

Figure 1 shows an outline drawing of the unit. The system block diagram is shown in Figure 2.

II. OBJECTIVE

The object of this study is to evaluate gyrocompass performance of NFM Serial no. 01-100. Gyrocompass performance evaluation includes determination of absolute azimuth accuracy and repeatability.

III. PROCEDURE

The NFM was installed on a mounting stand, Figure 3, by alignment pins and cam locks. The NFM was aligned with the alignment pins and pressed firmly against four mounting pads. The mounting pads were machined so that

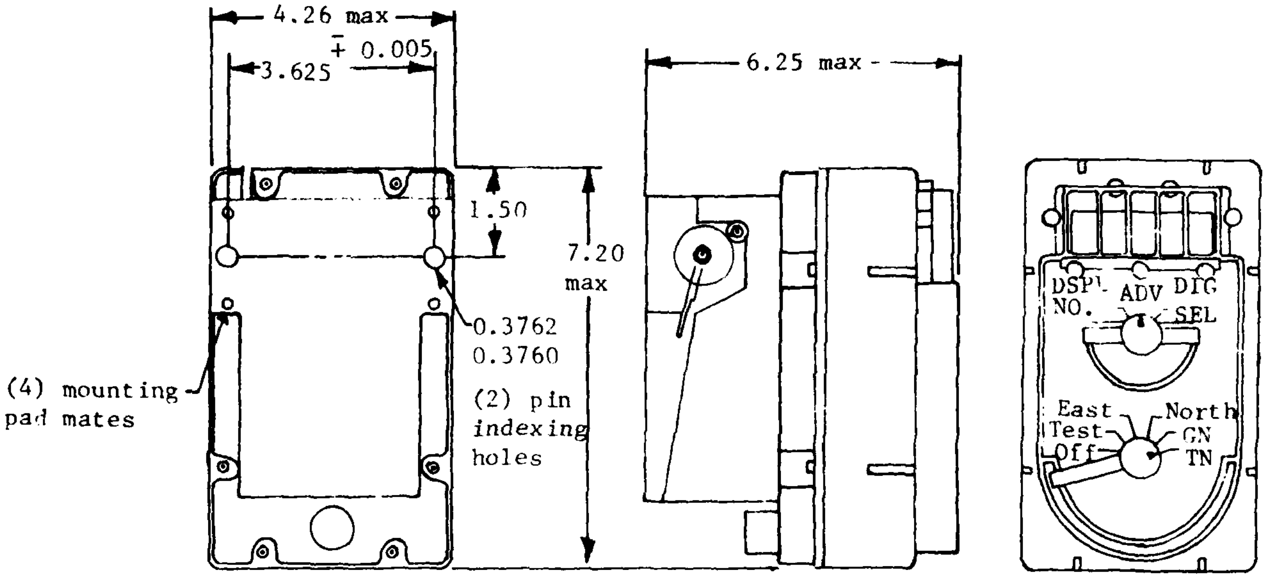


Figure 1. North-finding module.

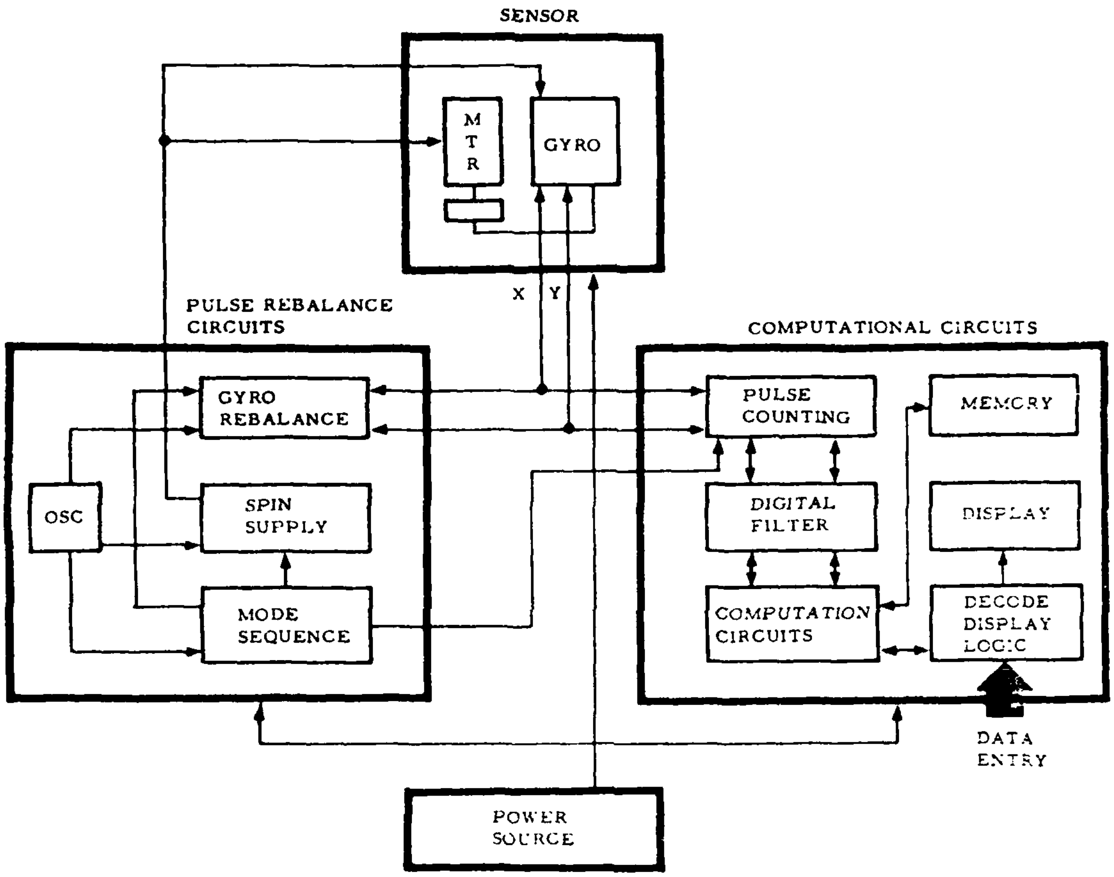


Figure 2. Block diagram of NFM.

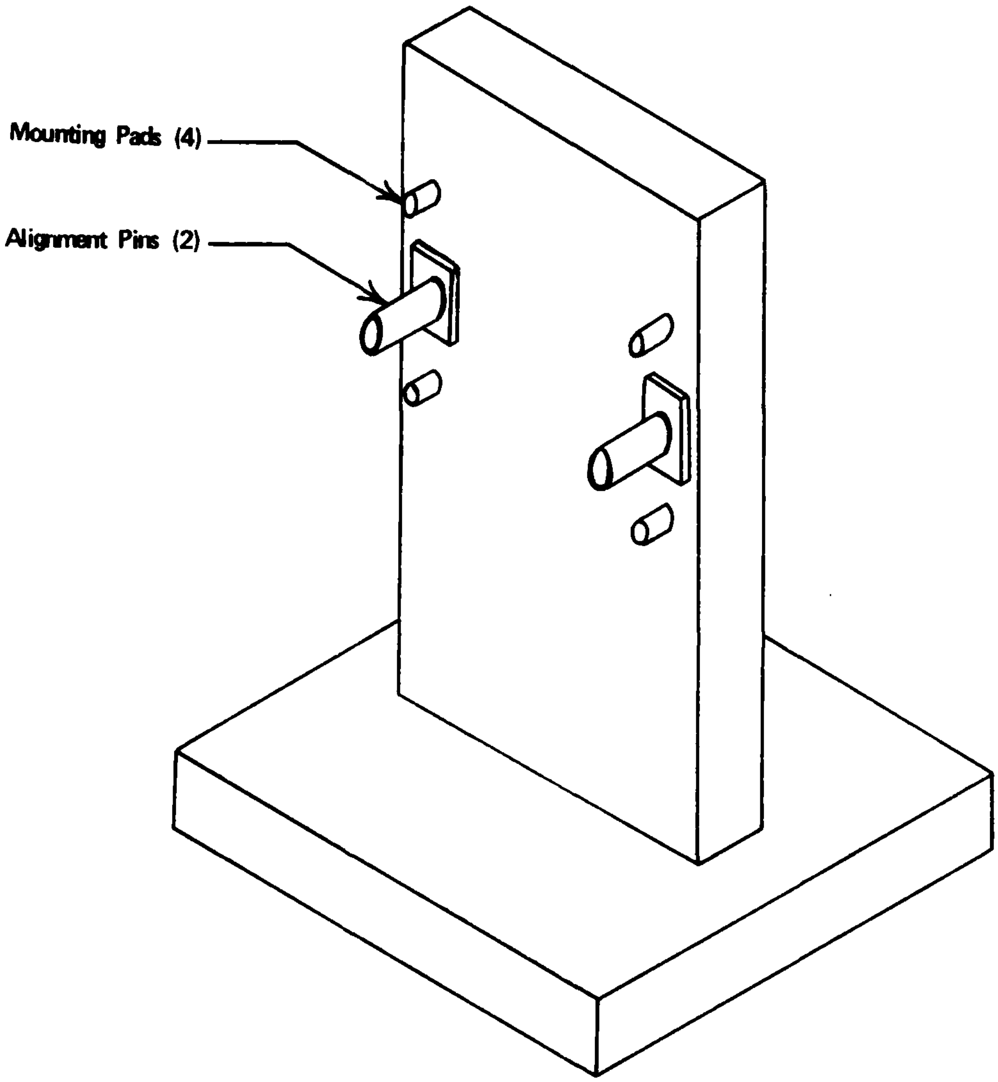


Figure 3. NFM mounting stand.

the plane formed by the pads was perpendicular to the line-of-sight (LOS) of the NFM. The mounting stand was bolted to a Pratt and Whitney 10 in. tilting rotary table.

To obtain the LOS of the NFM, the azimuth of the perpendicular to the plane of the mounting pads was determined. (See Appendix A for azimuth determination.) The rotary table was then set so that the LOS of the NFM was north (0°). The NFM was energized and initialized so that it gyrocompassed for 3 minutes and 55 seconds. The NFM reading was recorded, and the table was rotated through 45°. This process was repeated eight times after which the table was reset to north (0°).

The raw data is shown in Appendix B.,

IV. DISCUSSION OF RESULTS

Appendix C shows gyrocompassing results.

A study of the errors shows that, although a bias is evident, the NFM repeats acceptably.

As can be seen in Appendix C the standard deviation is close to the desired 0.25-mil error. Appendix C also shows that with the bias eliminated the root mean square (RMS) error decreases and approaches the one-sigma value which is less than 0.25 mil.

V. CONCLUSIONS

This study shows that, in a laboratory environment, the NFM can determine azimuth heading with reasonable accuracy.

Although the NFM has a bias, this offset can be eliminated electronically, mechanically, or preferably in software. Appendix D shows laboratory bias elimination calculations. With bias elimination, the RMS error is 0.23 mil (Run 3) which points to the possibility of obtaining 0.25 mil in a less benign, field environment.

These results were obtained even though the NFM gyrocompass time was 3 minutes and 55 seconds rather than the allowable goal of 5 minutes. An additional 1 minute of time would be expected to improve results.

The level requirement of $\pm 1/2$ degree would cause problems to a user. The desired goal for field use is $\pm 10^{\circ}$ off-level. This can theoretically be obtained by increasing clearance between the active element and the case. Also, it is expected that desensitization to environmental disturbance would be required for usage in the field.

The unit shows potential for use in an azimuth heading transfer system for tactical missile systems which do not have the on-board capability to self-align. The unit will be utilized in an in-house program to demonstrate this feasibility.

Appendix A
TEST PROCEDURE

Gyrocompass accuracy data was acquired using two theodolites, T1 and T2, and the Redstone Arsenal Astro Observation Point Monument, RA. The measurement diagram is shown in Figure A-1 in which the following definitions apply:

1) R1 = T1 horizontal scale reading when sighting from T1 to RA
2) R2 = T1 horizontal scale reading when sighting from T1 to T2
3) R3 = T2 horizontal scale reading when sighting from T2 to T1
4) R4 = T2 horizontal scale reading when sighting from T2 to the mounting stand.

Using Figure A-1 and the foregoing definitions, the following angles are known or can be calculated as indicated:

1) α = known angle between north and LOS to RA, $88^{\circ}\ 48'\ 48''$
2) $\beta = R2 - R1$
3) $\zeta = \alpha + \beta$
4) $\partial = R4 - R3$
5) $\Theta = \partial - 180^{\circ}$
6) $\varepsilon = \zeta + \Theta$

Entries necessary for calculation of ε were made Data Sheet No. 1.

Optical readings R1, R2, and R3 were determined by the average of two sets of forward and reverse measurements made with the applicable theodolite.

To determine R4, the LOS of the plane formed by the mounting pads had to be determined. This was accomplished with the use of a mirror rigidly attached to a flat plate. The plate was placed on the mounting stand so that it was in intimate contact with the mounting pads. Two sets of forward and reverse measurements were taken, and the average was recorded. The plane, formed by the mounting pads, and the mirror surface were not parallel, so the plate was rotated 180° so that the top of the plate was down. Two sets of forward and reverse measurements were taken and the average recorded.

As can be seen in the raw data in Appendix B, an azimuth difference indeed did occur after the plate was rotated. Figure A-2A shows the azimuth difference, ψ. The actual R4 was determined by bisecting ψ. (See Figure A-2B.) Bisected ψ was calculated by determining the average of the readings with the top of the plate up and the average of the readings with the top of the plate down (R4 readings).

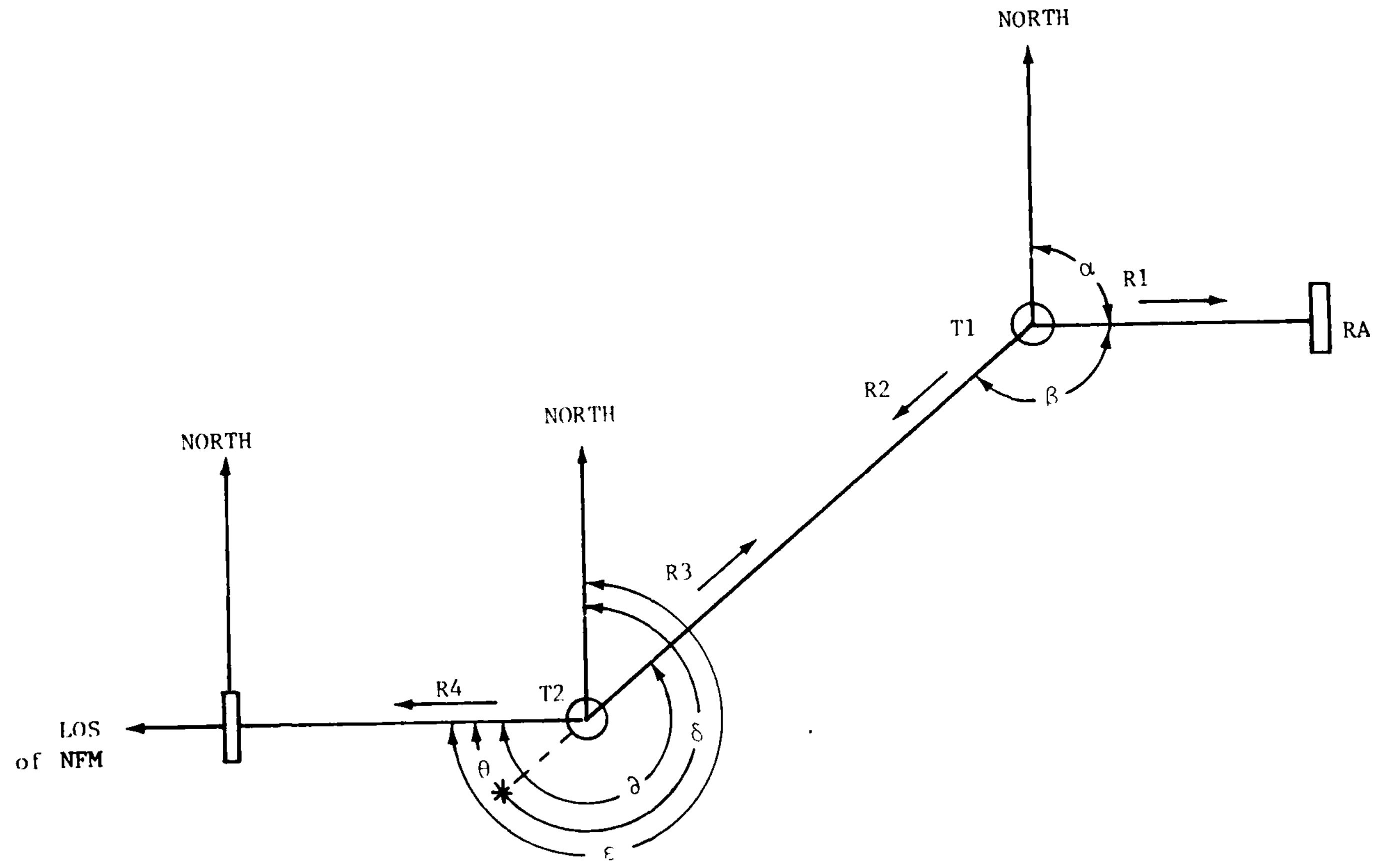


Figure A-1. Optical measurement diagram.

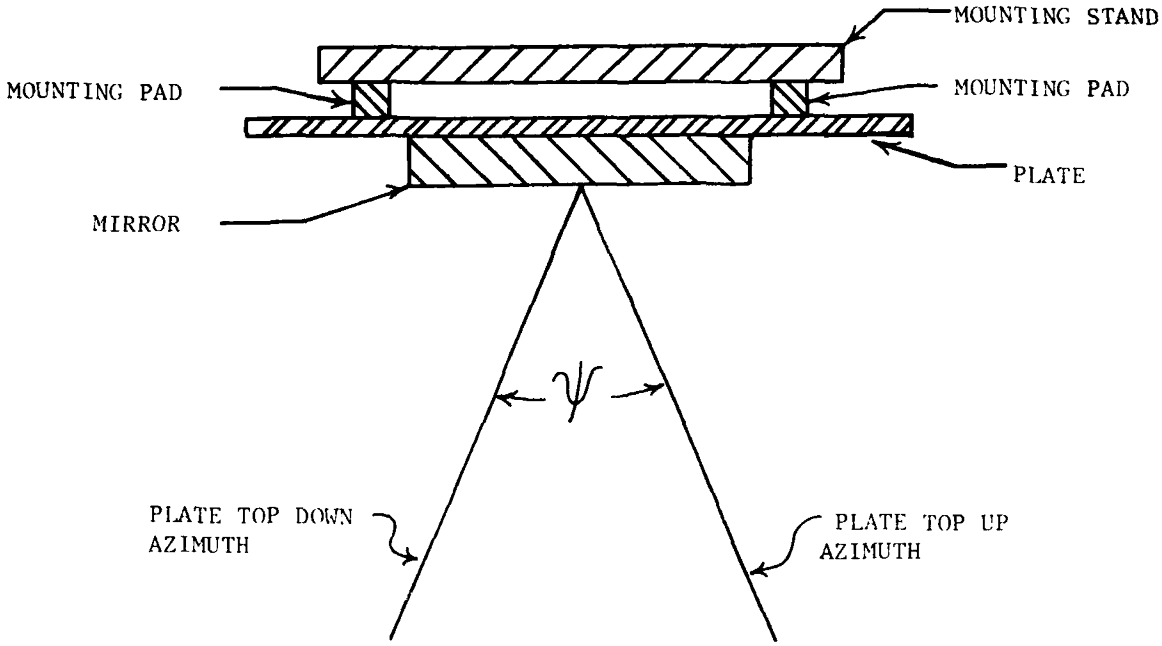


Figure A-2A. Azimuth difference, ψ, occurring when mirror is rotated.

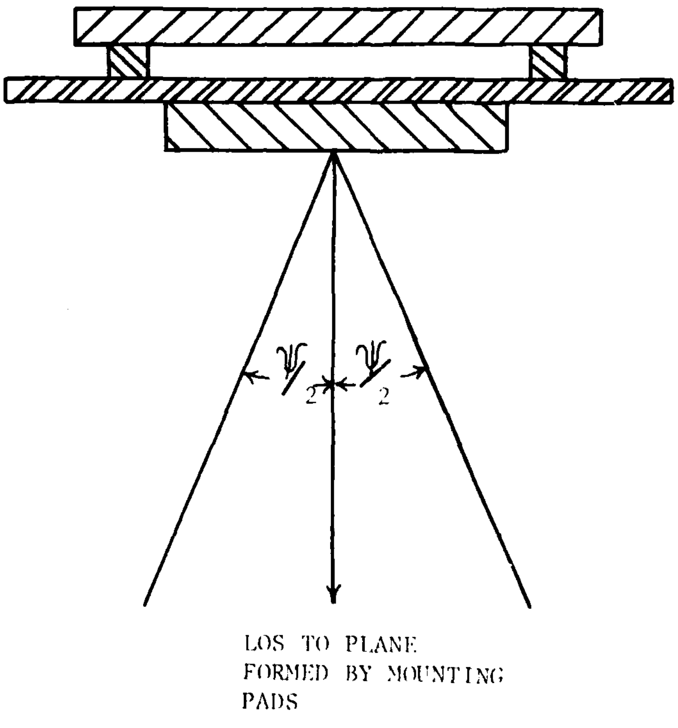


Figure A-2B. LOS to mounting pad plane determined by bisecting ψ.

Data Sheet No. 1
AZIMUTH DETERMINATION

Run No.:

T1 S/N:

T2 S/N:

Date :

Optical Data (deg, min, sec)

R2 =

R1 = ________

(β = R2 - R1) : β =

α = 088° 48' 48"

($\zeta = \alpha + \beta$) : ζ =

R4 =

R3 = ________

(∂ = R4 - R3) : ∂ =

180° 00' 00"

($\Theta = \partial - 180^\circ$) : Θ =

ζ = ________

($\varepsilon = \zeta + \Theta$) : ε =

Appendix B
RAW DATA

The following raw data was taken in the Clean Room facility in Building 5400.

Raw optical data (theodolite readings) corresponding to the requirements (minimum of two sets of forward and reverse measurements) of Appendix A are presented in Table B-1. Tables B-2 through B-4 present results of raw data reduction using the optical measurement diagram of Figure A-1, Appendix A.

NFM easting and northing inputs and output data are presented in Tables B-5 through B-8. Predelivery data taken by Litton are included.

TABLE B-1. THEODOLITE READINGS
(deg, min, sec)

Run no	R1 Fwd	R1 Rev	R2 Fwd	R2 Rev	R3 Fwd	R3 Rev	R4 Top up Fwd	R4 Top up Rev	R4 Top down Fwd	R4 Top down Rev
1	000 00 23	180 00 22	159 43 15	339 43 06	157 42 18	337 42 23	345 07 50	165 07 47	345 03 22	165 03 22
	22	23	16	07	17	20	47	50	23	22
							345 07 48		345 03 22	
	AVG: 000 00 22		159 43 11		157 42 20		345 05 35			
2	*	*	159 43 16	339 43 03	157 42 27	337 42 22	345 07 50	165 07 49	345 03 45	165 03 45
			14	07	24	25	47	50	44	44
							345 07 49		345 03 44	
	AVG: 000 00 22		159 43 10		157 42 24		345 05 46			
3	000 00 27	180 00 21	159 47 39	339 47 29	132 02 03	312 02 03	152 00 02	332 00 05	152 04 12	332 04 12
	28	22	41	24	00	04	05	06	13	14
							152 00 04		152 04 13	
	AVG: 000 00 24		159 47 33		132 02 02		152 02 08			

* Adverse weather conditions prohibited outside reading. Eighty percent of previous measurements indicate reading of 00° 00' 22"

TABLE B-2. AZIMUTH DETERMINATION

Run No.: 1

T1 S/N : 116699 (Hilgar Watts ST200)

T2 S/N : 55942 (Wild T2)

Date : 23 Mar 81

Optical Data (deg, min, sec)

$$
\begin{array}{rl}
 & R2 = 159\ 43\ 11 \\
 & R1 = \underline{000\ 00\ 22} \\
(\beta = R2 - R1): & \beta = 159\ 42\ 49 \\
 & \alpha = \underline{088\ 48\ 48} \\
(\zeta = \alpha + \beta): & \zeta = 248\ 31\ 37
\end{array}
$$

$$
\begin{array}{rl}
 & R4 = 345\ 05\ 35 \\
 & R3 = \underline{157\ 42\ 20} \\
(\partial = R4 - R3): & \partial = 187\ 23\ 15 \\
 & \underline{180\ 00\ 00} \\
(\Theta = \partial - 180^{\circ}): & \Theta = 007\ 23\ 15 \\
 & \zeta = \underline{248\ 31\ 37} \\
(\varepsilon = \zeta + \Theta): & \varepsilon = 255\ 54\ 52
\end{array}
$$

TABLE B-3. AZIMUTH DETERMINATION

Run No.: 2

T1 S/N : 116699 (Hilgar Watts ST200)

T2 S/N : 55942 (Wild T2)

Date : 24 Mar 81

Optical Data (deg, min, sec)

	R2 = 159 43 10
	R1 = 000 00 22
(β = R2 - R1) :	β = 159 42 48
	α = 088 48 48
($\zeta = \alpha + \beta$) :	ζ = 248 31 36
	R4 = 345 05 46
	R3 = 157 42 24
(∂= R4 - R3) :	∂ = 187 23 22
	180 00 00
($\Theta = \partial - 180$) :	Θ = 007 23 22
	ζ = 248 31 36
($\varepsilon = \zeta + \Theta$) :	ε = 255 54 58

TABLE B-4. AZIMUTH DETERMINATION

Run No.: 3

T1 S/N : 116699 (Hilgar Watts ST200)

T2 S/N : 55942 (Wild T2)

Date : 31 Mar 81

Optical Data (deg, min, sec)

	R2 =	159 47 33
	R1 =	000 00 24
$(\beta = R2 - R1)$:	β =	159 47 09
	=	088 48 48
$(\zeta = \alpha + \beta)$:	ζ =	248 35 57
	R4 =	152 02 08
	R3 =	132 02 02
$(\partial = R4 - R3)$:	∂ =	020 00 06
		180 00 00
$(\Theta = \partial - 180)$:	Θ =	-159 59 54
	ζ =	248 35 57
$(\varepsilon = \zeta + \Theta)$:	ε =	088 36 03

TABLE B-5. NFM OUTPUT DATA

Run No. : 1

Easting : 999

Northing: 8200

Warm-up time: cold start

Date: 23 Mar 81

Set No.	Heading (mil) (deg)							
	0000.00 0	0800.0 45	1600.00 90	2400.0 135	3200.0 180	4000.00 225	4800.0 270	5600.0 315
1	0001.3	0800.6	1600.0	2400.4	3200.5	4000.0	4799.9	5600.3
2	0000.4	0800.6	1600.1	2400.6	3200.4	4000.1	4800.4	5600.4
3	0000.5	0800.2	1600.3	2400.0	3200.2	3999.9	4799.9	5600.6
4	0000.5	0799.8	1600.4	2400.3	3200.2	4000.6	4800.0	5600.3
5	0000.7	0800.2	1600.1	2400.3	3200.2	4000.6	4800.0	5600.3
6	0000.3	0800.5	1599.9	2400.2	3200.1	4000.0	4800.1	5600.4
7	0000.3	0800.2	1600.4	2400.3	3200.3	4000.4	4800.0	5600.2

Table entries are in mils

TABLE B-6. NFM OUTPUT DATA

Run No. : 2

Easting : 999

Northing: 8200 Warm-up time: cold start Date: 24 Mar 81

Set No.	Heading (mil) (deg)	0000.0 0	0800.0 45	1600.0 90	2400.0 135	3200.0 180	4000.0 225	4800.0 270	5600.0 315
1		0000.6	0800.4	1600.1	2400.5	3200.0	3999.7	4799.6	5600.1
2		0000.5	0800.4	1600.1	2400.4	3200.3	4000.0	4799.9	5600.3
3		0000.4	0800.5	1600.0	2400.0	3200.8	4000.2	4799.6	5600.2
4		0000.7	0800.0	1599.9	2400.3	3200.2	4000.3	4800.0	5600.2
5		0000.7	0800.3	1600.1	2400.3	3200.3	4000.1	4800.1	5600.2
6		0000.4	0799.8	1600.0	2400.3	3200.3	4000.5	4799.5	5599.9
7		0000.3	0800.1	1600.0	2400.3	3200.4	4000.3	4799.7	5600.1
8		0000.2	0799.6	1599.8	2400.0	3200.0	4000.3	4799.2	5600.2
9		0000.4	0800.0	1600.0	2400.2	3200.1	3999.9	4799.9	5600.0
10		0000.6	0800.0	1600.0	2400.4	3200.1	4000.0	4799.7	5599.9

Table entries are in mils

TABLE B-7. NFM OUTPUT DATA

Run No. : 3

Easting : 997

Northing: 8200

Warm-up time: 2hr 45min   Date: 31 Mar 81

Note: The table was rotated 30 arc sec to eliminate the bias.

Heading (mil)	0000.0	0800.0	1600.0	2400.0	3200.0	4000.0	4800.0	5600.0
(deg)	0	45	90	135	180	225	270	315
Set No.								
1	0000.5	0800.3	1599.9	2400.0	3200.2	3999.9	4799.5	5600.0
2	0000.4	0800.6	1599.9	2399.7	3200.3	3999.9	4799.9	5599.9
3	0000.2	0800.4	1600.2	2400.0	3200.2	3999.8	4799.9	5599.9
4	0000.1	0800.0	1600.0	2400.0	3200.1	3999.8	4799.8	5600.2
5	0000.1	0800.1	1599.7	2399.7	3199.8	4000.0	4800.0	5599.8

Table entries are in mils

TABLE B-8. NFM PREDELIVERY OUTPUT DATA

Easting : 999

Date: 11 Mar 81

Northing: 3782

Set No.	Heading (mil) (deg)	0000.0 0	0800.0 45	1600.0 90	2400.0 135	3200.0 180	4000.0 225	4800.0 270	5600.0 315
1		0000.1	0800.4	1600.2	2400.4	3199.8	3999.9	4799.5	5600.6
2		0000.2	0800.6	1599.9	2400.1	3200.4	4000.1	4799.5	5600.3
3		0000.1	0799.3	1600.2	2400.5	3200.2	4000.7	4800.0	5600.0
4		0000.2	0800.0	1600.0	2400.3	3200.2	4000.0	4799.3	5600.3

Table entries are in mils

Appendix C
DATA REDUCTION AND RESULTS

The error, E, in each gyrocompass run, as shown in Tables C-1 through C-4, was determined by the difference in NFM output, O, and actual heading, AH.

$$E = O - AH$$

The root mean square (RMS), mean ($\bar{X}$), and standard deviation (σ) of the errors were determined for each heading and each run of each set.

The RMS for each heading, RMS_h, was determined by:

$$RMS_h = \left(\frac{\sum_{i=1}^{n} (E_i)^2}{n} \right)^{1/2}, \quad n = \text{number of readings at a given heading.}$$

The composite RMS for each run, RMS_r, was determined by:

$$RMS_r = \left(\frac{\sum_{i=1}^{n} \left(RMS_{h_i}\right)^2}{n} \right)^{1/2}, \quad n = \text{number of headings} = 8.$$

The mean for each heading, $\bar{X}_h$, was determined by:

$$\bar{X}_h = \frac{\sum_{i=1}^{n} E_i}{n}, \quad n = \text{number of readings at a given heading.}$$

The composite mean for each run, $\bar{X}_r$, was determined by:

$$\bar{X}_r = \frac{\sum_{i=1}^{n} \bar{X}_{h_i}}{n}, \quad n = \text{number of headings} = 8.$$

The standard deviation for each heading, σ_h, was determined by:

$$\sigma_h = \left(\frac{\sum_{i=1}^{n} \left(E_i - \bar{X}_h\right)^2}{n-1} \right)^{1/2}, \quad n = \text{number of readings at a given heading.}$$

The composite standard deviation for each run, σ_r, was determined by:

$$\sigma_r = \left(\frac{\sum_{i=1}^{n} \left(E_i - \overline{X}_r \right)^2}{n-1} \right)^{1/2}$$, n = total number of readings in a given run.

The composite randomness for each run, R_r , was determined by:

$$R_r = \left(\frac{\sum_{i=1}^{n} \left(\sigma_{h_i} \right)^2}{n} \right)^{1/2}$$, n = number of headings = 8.

The results are shown in Table C-5.

The mean error data contained in Table C-5 are plotted in Figures C-1 through C-4.

Figure C-5 shows histograms of the gyrocompass errors.

TABLE C-1. GYROCOMPASS ERRORS, E

Date: 23 Mar 81

Run No.: 1

Heading (mil) (deg)	0000.0 0	0800.0 45	1600.0 90	2400.0 135	3200.0 180	4000.0 225	4800.0 270	5600.0 315
Set No. 1	1.3	0.6	0.0	0.4	0.5	0.0	-.1	0.3
2	0.4	0.6	0.1	0.6	0.4	0.1	0.4	0.4
3	0.5	0.2	0.3	0.0	0.2	-.1	-.1	0.6
4	0.5	-.2	0.4	0.3	0.2	0.6	0.0	0.3
5	0.7	0.2	0.1	0.3	0.2	0.6	0.0	0.3
6	0.3	0.5	-.1	0.2	0.1	0.0	0.1	0.4
7	0.3	0.2	0.4	0.3	0.3	0.4	0.0	0.2

Table entries are in mils

TABLE C-2. GYROCOMPASS ERRORS, E

Run No.: 2 Date: 24 Mar 81

Set No.	Heading (mil) (deg)	0000.0 0	0800.0 45	1600.0 90	2400.0 135	3200.0 180	4000.0 225	4800.0 270	5600.0 315
1		0.6	0.4	0.1	0.5	0.0	-.3	-.4	0.1
2		0.5	0.4	0.1	0.4	0.3	0.0	-.1	0.3
3		0.4	0.5	0.0	0.0	0.8	0.2	-.4	0.2
4		0.7	0.0	-.1	0.3	0.2	0.3	0.0	0.2
5		0.7	0.3	0.1	0.3	0.3	0.1	0.1	0.2
6		0.4	-.2	0.0	0.3	0.3	0.5	-.5	-.1
7		0.3	0.1	0.0	0.3	0.4	0.3	-.3	0.1
8		0.2	-.4	-.2	0.0	0.0	0.3	-.8	0.2
9		0.4	0.0	0.0	0.2	0.1	-.1	-.1	0.0
10		0.6	0.0	0.0	0.4	0.1	0.0	-.3	-.1

Table entries are in mils

TABLE C-3. GYROCOMPASS ERRORS, E

Date: 31 Mar 81

Run No. 3*

Heading (mil) (deg)	0000.0 0	0800.0 45	1600.0 90	2400.0 135	3200.0 180	4000.0 225	4800.0 270	5600.0 315
Set No.								
1	0.5	0.3	-.1	0.0	0.2	-.1	-.5	0.0
2	0.4	0.6	-.1	-.3	0.3	-.1	-.1	-.1
3	0.2	0.4	0.2	0.0	0.2	-.2	-.1	-.1
4	0.1	0.0	0.0	0.0	0.1	-.2	-.2	0.2
5	0.1	0.1	-.3	-.3	-.2	0.0	0.0	-.2

Table entries are in mils

* This run was made with bias compensation. The bias was removed by rotating the rotary table 30 arc sec. See Appendix B, Table B-7.

TABLE C-4. GYROCOMPASS ERRORS, E

Predelivery data

Date: 11 Mar 81

Heading (mil) (deg)	0000.0 0	0800.0 45	1600.0 90	2400.0 135	3200.0 180	4000.0 225	4800.0 270	5600.0 315
Set No. 1	0.1	0.4	0.2	0.4	-.2	-.1	-.5	0.6
2	0.2	0.6	-.1	0.1	0.4	0.1	-.5	0.3
3	0.1	-.7	0.2	0.5	0.2	0.7	0.0	0.0
4	0.2	0.0	0.0	0.3	0.2	0.0	-.7	0.3

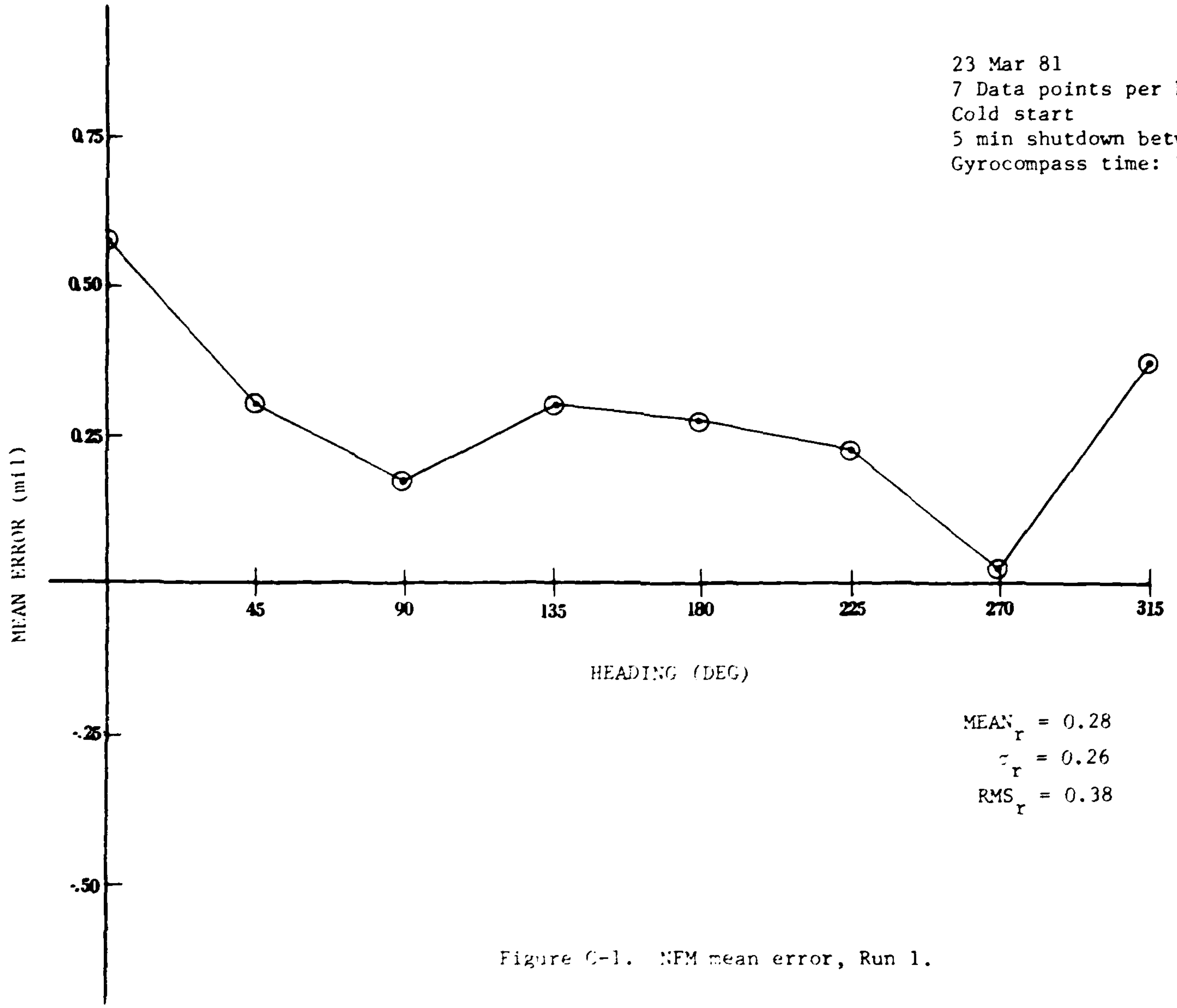
Table entries are in mils

TABLE C-5. GYROCOMPASS TEST RESULTS

Heading (mil)	Statistic	Run No. 1	Run No. 2	Run No. 3*	Predelivery data
		(mils)			
0000.0	RMS_h	0.65	0.51	0.31	0.16
	$\bar{X}_h$	0.57	0.48	0.26	0.15
	σ_h	0.35	0.17	0.18	0.06
0800.0	RMS_h	0.40	0.29	0.35	0.50
	$\bar{X}_h$	0.30	0.11	0.28	0.07
	σ_h	0.29	0.29	0.24	0.57
1600.0	RMS_h	0.25	0.09	0.17	0.15
	$\bar{X}_h$	0.17	0.00	-0.06	0.07
	σ_h	0.20	0.09	0.18	0.15
2400.0	RMS_h	0.34	0.31	0.19	0.36
	$\bar{X}_h$	0.30	0.27	-0.12	0.33
	σ_h	0.18	0.16	0.16	0.17
3200.0	RMS_h	0.30	0.34	0.21	0.26
	$\bar{X}_h$	0.27	0.25	0.12	0.15
	σ_h	0.14	0.24	0.19	0.25
4000.0	RMS_h	0.36	0.26	0.14	0.36
	$\bar{X}_h$	0.23	0.13	-0.12	0.17
	σ_h	0.30	0.24	0.08	0.36
4800.0	RMS_h	0.16	0.38	0.25	0.50
	$\bar{X}_h$	0.04	-0.28	-0.18	-0.57
	σ_h	0.17	0.27	0.19	0.30
5600.0	RMS_h	0.38	0.17	0.14	0.37
	$\bar{X}_h$	0.36	0.11	-0.04	0.30
	σ_h	0.13	0.14	0.15	0.24
Composite Statistics	RMS_r	0.38	0.32	0.23	0.36
	$\bar{X}_r$	0.28	0.13	0.02	0.10
	σ_r	0.26	0.29	0.23	0.34
	R_r	0.23	0.21	0.18	0.30

* Run 3 was made with bias removed. See Appendix B, Table B-7.

23 Mar 81
7 Data points per heading
Cold start
5 min shutdown between last 3 runs
Gyrocompass time: 3 min 55 sec



$MEAN_r = 0.28$
$\sigma_r = 0.26$
$RMS_r = 0.38$

Figure C-1. NFM mean error, Run 1.

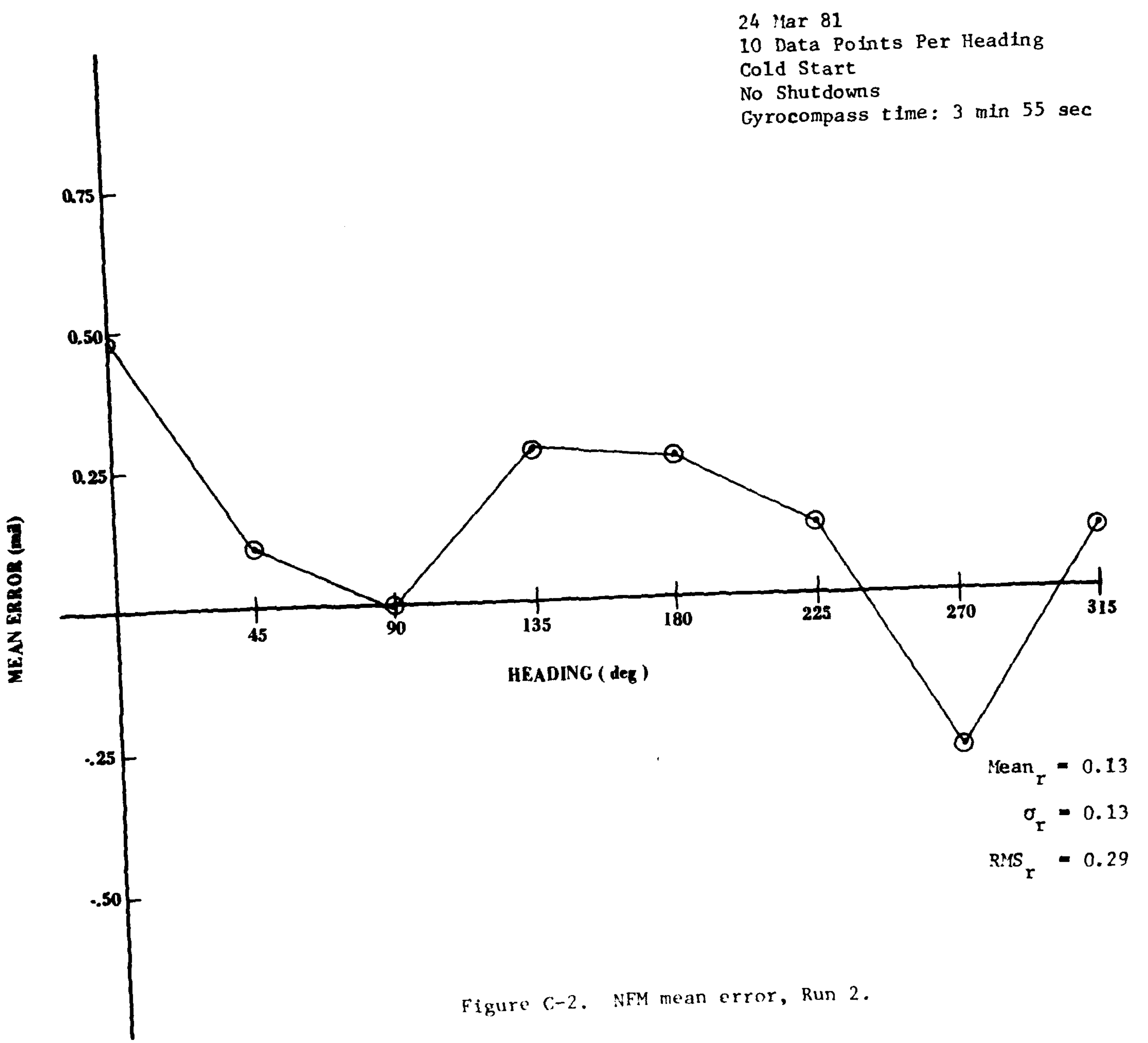


Figure C-2. NFM mean error, Run 2.

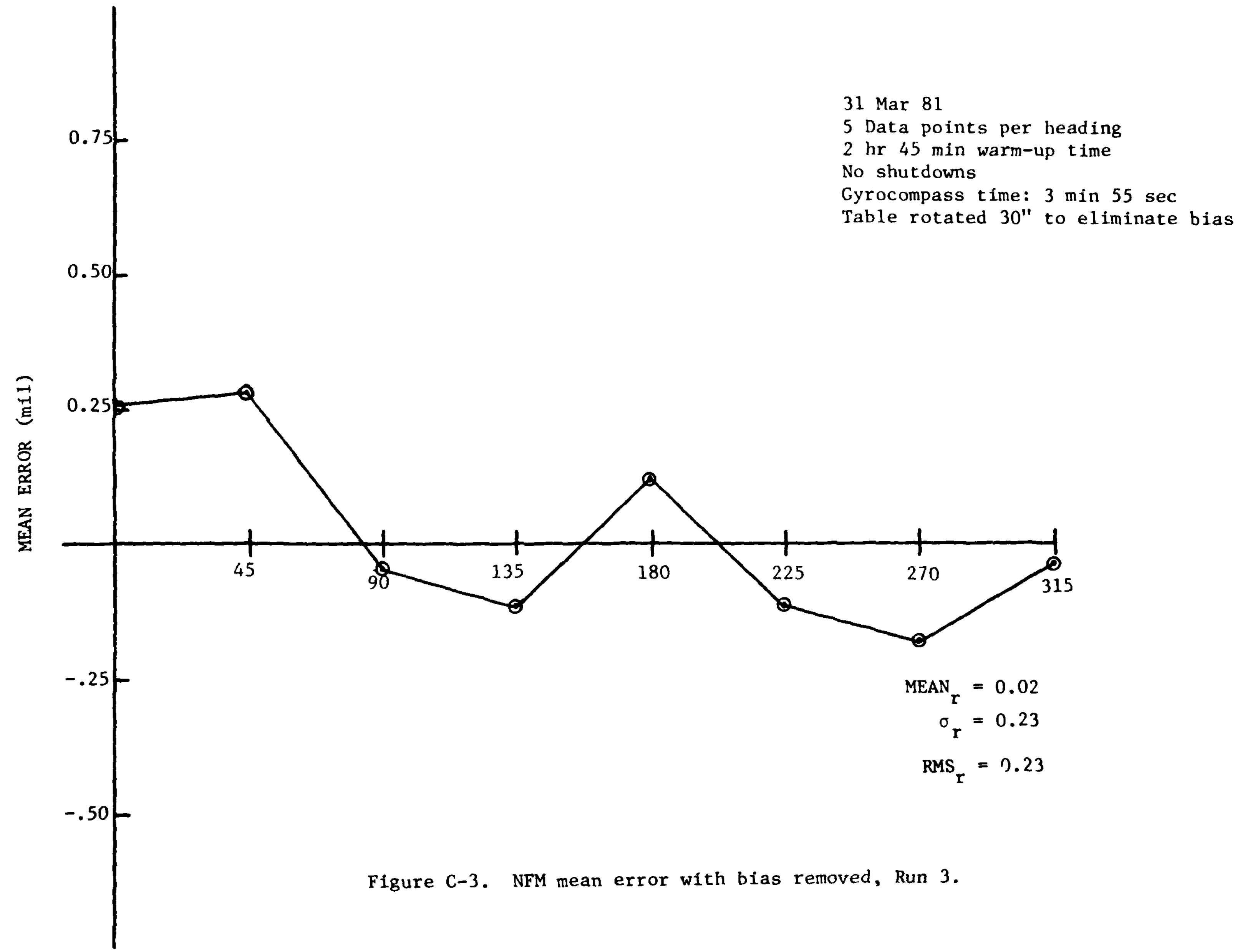


Figure C-3. NFM mean error with bias removed, Run 3.

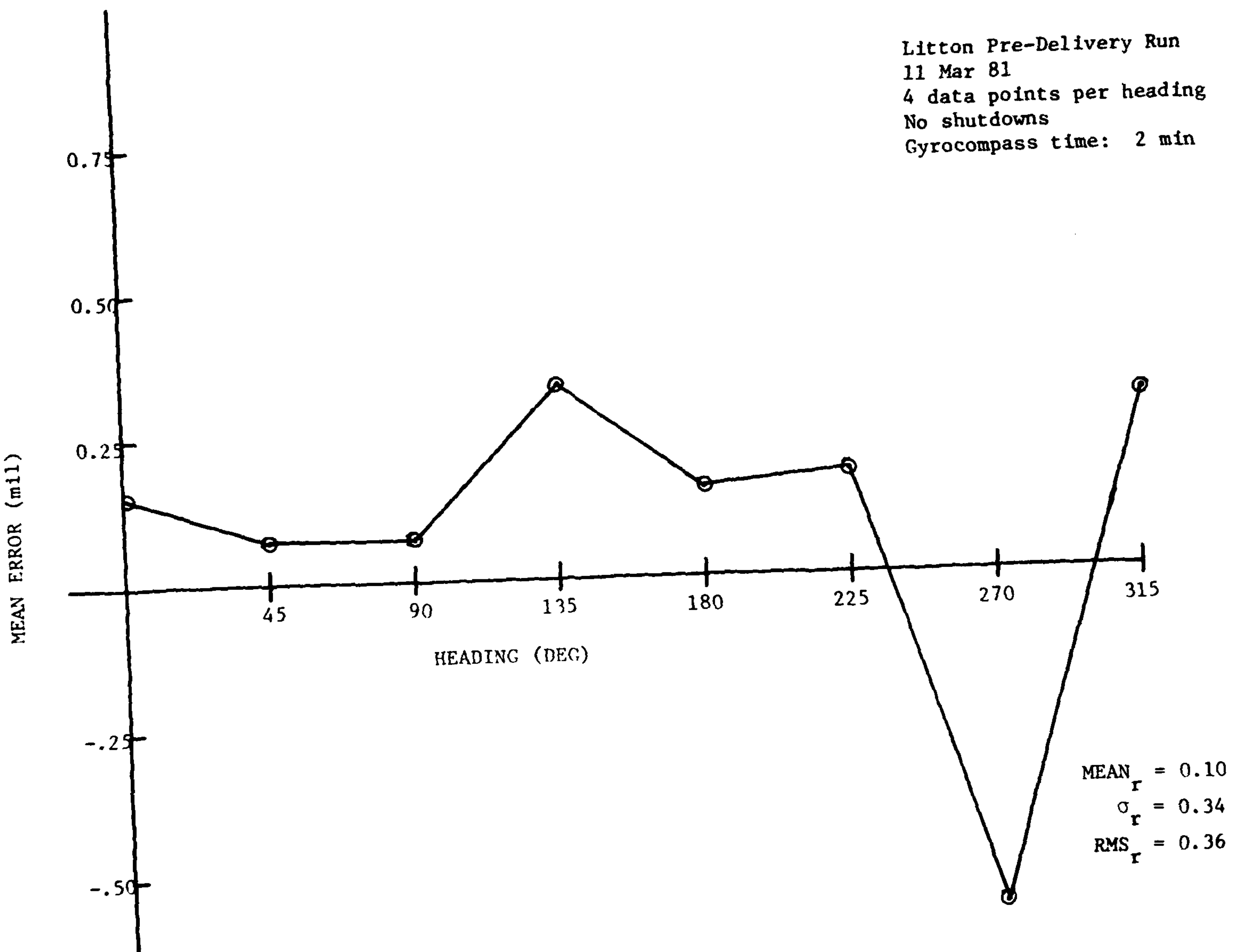
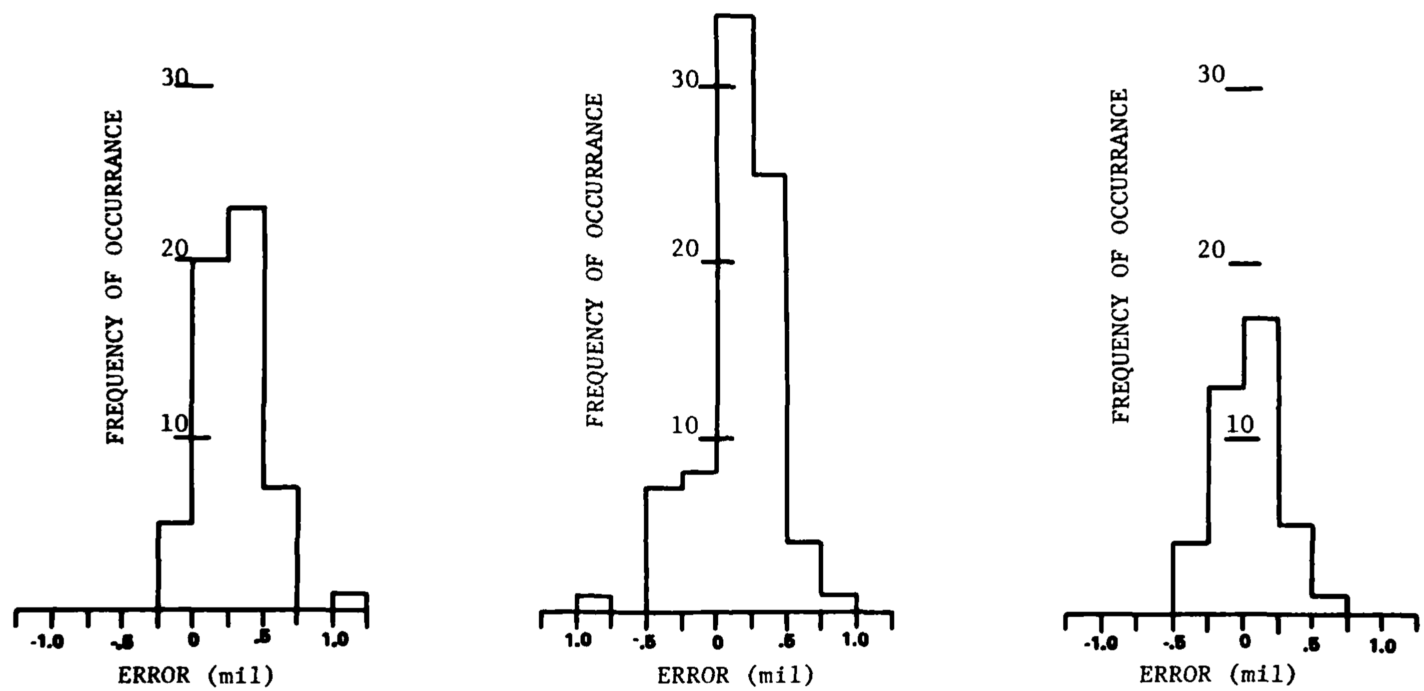


Figure C-4. NFM mean error, pre-delivery data.



Run No. 1
23 Mar 81
7 runs/hdg; 56 pts
RMS = 0.38
$\bar{x}$ = 0.28
σ = 0.26

Run No. 2
24 Mar 81
10 runs/hdg; 80 pts
RMS = 0.32
$\bar{x}$ = 0.13
σ = 0.29

Run No. 3*
31 Mar 81
5 runs/hdg; 40 pts
RMS = 0.23
$\bar{x}$ = 0.02
σ = 0.23

*Bias removed

Figure C-5. Histograms of errors.

Appendix D
BIAS DETERMINATION

Since Runs 1 and 2 consisted of unequal amounts of data points, a mean bias was determined by an appropriate percentage of each run's mean. Run 1 was weighted by 7/17 and Run 2 was weighted by 10/17. A mean bias, $\overline{X}_B$, was calculated thusly:

$$\overline{X}_B = \frac{7(0.28 \text{ mil}) + 10(0.13 \text{ mil})}{17} = 0.19 \text{ mil} = 38 \text{ arc sec}$$

A run was made with the rotary table rotated counterclockwise 38 arc sec from true heading but the resulting mean was -0.10 mil, which indicated the table had been rotated too much.

Another run, Run 3, was made with the table rotated 0.15 mil (30 arc sec). The resulting mean was 0.02 mil which indicated that the offset was essentially eliminated.

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